#4
5-15-0

OIPE JG54
MAY 0 1 2002
PATENT & TRADEMARK OFFICE

Please type a plus sign (+) inside this box → [+]

PTO/SB/21 (08-00)
Approved for use through 10/31/2002. OMB 0651-0031
Patent and Trademark Office: U.S. DEPARTMENT OF COMMERCE
Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number.

RECEIVED
MAY -2 2002
TECHNOLOGY CENTER 2800

TRANSMITTAL FORM

(to be used for all correspondence after initial filing)

Application	10/005,166
Filing Date	December 7, 2001
First Named	MIHELCIC, Joe
Group Art Unit	2872
Examiner Name	
Attorney Docket Number	3342077.0005

Total Number of Pages in This Submission

ENCLOSURES *(check all that apply)*

- [ ] Fee Transmittal Form
  - [ ] Fee Attached
- [ ] Amendment / Response
  - [ ] After Final
  - [ ] Affidavits/declaration(s)
- [ ] Extension of Time Request
- [ ] Express Abandonment Request
- [ ] Information Disclosure Statement
- [X] Certified Copy of Priority Document(s)
- [ ] Response to Missing Parts/ Incomplete Application
  - [ ] Response to Missing Parts under 37 CFR 1.52 or 1.53
- [ ] Assignment Papers *(for an Application)*
- [ ] Drawing(s)
- [ ] Licensing-related Papers
- [ ] Petition
- [ ] Petition to Convert a Provisional Application
- [ ] Power of Attorney, Revocation Change of Correspondence
- [ ] Terminal Disclaimer
- [ ] Request for Refund
- [ ] CD, Number of CD(s) ________
- [ ] After Allowance Communication to Group
- [ ] Appeal Communication to Board of Appeals and Interferences
- [ ] Appeal Communication to Group (*Appeal Notice, Brief, Reply Brief*)
- [ ] Proprietary Information
- [ ] Status Letter
- [X] Other Enclosure(s) *(please identify below)*:

Letter re: Priority Claim

Remarks

SIGNATURE OF APPLICANT, ATTORNEY, OR AGENT

Firm or Individual name	PILLAY, Kevin Reg. No. 41,559
Signature	
Date	April 30, 2002

CERTIFICATE OF MAILING

I hereby certify that this correspondence is being deposited with the United States Postal Service with sufficient postage as first class mail in an envelope addressed to: Commissioner for Patents, Washington, D.C. 20231 on this date:

Typed or printed name			
Signature		Date	

Burden Hour Statement: This form is estimated to take 0.2 hours to complete. Time will vary depending upon the needs of the individual case. Any comments on the amount of time you are required to complete this form should be send to the Chief Information Officer, U. S. Patent and Trademark Office, Washington, DC 20231. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Assistant Commissioner for Patents, Washington, DC 20231.

OIPE JC54 MAY 0 1 2002 PATENT & TRADEMARK OFFICE

ATTORNEY DOCKET NO.: 3342077.0005

IN THE UNITED STATES PATENT & TRADEMARK OFFICE

In re patent application of:

MIHELCIC, Joe

Serial No.: 10/005,166 Group Art Unit: 2872

Filed: December 7, 2001

Title: Method And System For Complete 3D Object And Area Digitizing

April 30, 2002

The Commissioner of Patents & Trademarks
Washington, D.C. 20231

PRIORITY CLAIM

Dear Sir:

The benefit of the filing date in Canada of a patent application corresponding to the above-identified application, is hereby claimed under Rules 37 CFR 1.55 and 35 U.S.C. 119 in accordance with the Paris Convention for the Protection of Industrial Property. A certified copy of the corresponding Canadian patent application bearing Serial No. 2,327,894 filed December 7, 2000, is submitted herewith.

Respectfully submitted,

April 30, 2002

Kevin Pillay
Agent for Applicant
Registration No. 41,559

Fasken Martineau DuMoulin LLP
Suite 4200, P.O. Box 20
Toronto Dominion Bank Tower
Toronto-Dominion Centre
Toronto, Ontario M5K 1N6
Telephone: (416) 868-3485
Facsimile: (416) 364-7813

RECEIVED
MAY -2 2002
TECHNOLOGY CENTER 2800

Office de la propriété intellectuelle du Canada
Un organisme d'Industrie Canada

Canadian Intellectual Property Office
An Agency of Industry Canada

Bureau canadien des brevets

Certification

La présente atteste que les documents ci-joints, dont la liste figure ci-dessous, sont des copies authentiques des documents déposés au Bureau des brevets.

Canadian Patent Office

Certification

This is to certify that the documents attached hereto and identified below are true copies of the documents on file in the Patent Office.

Specification and Drawings, as originally filed, with Application for Patent Serial No: **2,327,894**, on December 7, 2000, by **CLEARVIEW GEOPHYSICS INC.**, assignee of Joe Mihelcic, for "Method and System for Complete 3D Object and Area Digitizing".

L. Lachance

Agent certificateur/Certifying Officer

February 12, 2002

Date

Method and System for Complete 3D Object and Area Digitizing

TABLE of CONTENTS

1. INTRODUCTION

The invention is a flexible complete and efficient 3D scanning system and process for acquiring and locating real visual information, storing it with 3D coordinates, and processing it so that it can be used readily by a wide number of applications. The process consists of establishing a survey grid at the site, acquiring the data using a predetermined survey methodology, and subsequently post-processing the data so that it can be utilized by various applications software.

US Patent 5,870,220 Feb. 9, 1999; US Patent 5,973,788 Oct. 26, 1999, US Patent 6,094,269 July 25, 2000, and others, provide good sections describing the art background, although they are limited to object-scanning, whereas the present invention is fundamentally different and designed to scan areas and objects at any scale. These prior inventions can not be converted or modified to scan large areas due to fundamental design limitations (refer to Prior Art section at end of this document).

US Patent 5,675,407 Oct. 7, 1997, and others, provides a good prior art section for scanning objects or areas. It also discusses a novel method of scanning objects using various light spectrum. However, this patent does not address larger scale applications (e.g., stadium size or larger) and appears limited to object or small room, at best, scanning. US Patent 5,216,476 Jun. 1, 1993 has similar requirements as the present invention, but uses standard stereoscopic camera techniques, which are fundamentally very different and technically fall short from those proposed in this invention.

From the patents analyzed, there do not appear to be any past inventions that are similar to the total system concept of the present invention.

1.1 POTENTIAL APPLICATIONS

- Scene investigations, small or large scale, e.g., from a computer at other time and place.
- Roam area from remote location, e.g., over computer network.
- Computer graphics/displays, e.g., computer games with "real life images", manipulated in 3D.
- Moving picture scenes can be modified at other time and place, after scene has changed.
- Object digitization, small or large.
- Dangerous site exploration, e.g., apparatus acquires data that can be viewed at leisure at later time (e.g., space exploration, nuclear reactors, marine investigations).
- Simulations, e.g., flight simulators more life-like with real images.
- Full scans of movable objects (e.g., people), e.g., to allow computer manipulation/animation of real images for various requirements.
- Model Studies, e.g., scan real airplanes/cars/ships/buildings/bridges, etc. and use in computer simulations to predict structural failure points, etc.

1.2 BACKGROUND OF THE INVENTION

1.2.1 Specific Problems Faced and Specific Objections Sought to be Achieved

The invention is designed to acquire and register real images from an object or area, in all three dimensions, so that a user can view the target object or area regenerated on a computer at any viewpoint chosen, within the specifications defined from the survey goal. Problems overcome include:

- Built in flexibility for large- or small-scale surveys of objects or areas.
- Detailing a systematic approach, from defining the goal of the survey, to making the results available for a wide range of applications.
- Designed system for acquiring data efficiently and accurately without numerous calibrations and complicated calculations.
- Identified parameters that are important for configuring system (e.g. scale, resolution, accuracy, mode, etc.).
- Built systems for transporting and mounting assemblies (posts, rails, beams, etc.)
- Designed computer architecture for acquiring, cross-referencing, and processing extremely large data sets from multiple sources.
- Produced calibration methodology to account for unique camera lens parameters (e.g. focal length, distortion, etc.).
- Accounted for reduced accuracy due to greater distances between target object and apparatus (increased camera-laser separations) by defining "scanning ranges".

1.2.2 Disadvantages of Existing Systems

- Most existing systems are difficult to implement/complex, fail to describe an entire practical process, concentrate primarily on "object" scanning for manufacturing and quality control.

1.2.3 Manner in Which the Invention Solves the Problems and Disadvantages of Existing Systems

- The invention takes advantage of parallel computing power to handle multiple lasers and camera groups.
- The invention uses a systematic process on a grid pattern - can use "range finders", etc., to complement certain aspects of invention such as defining "camera-laser ranges".
- The Invention is designed for may survey beam angles to the camera direction, the entire assembly is moved and rotated. This greatly simplifies the calibration requirements and increases the system flexibility.

1.2.4 Features and Characteristics for which Protection will be Sought

- Complete process from start to finish, for any scale/resolution/accuracy.
- Parallel computer cluster for rapid and simple data acquisition and processing.

- Laser/camera "groups" and mounting/transport systems (e.g. trucks, beams, etc.).
- Simple and accurate camera calibration procedure.
- Determination of optimal camera-laser separations due to increased distance to targets.

2. CONCEPT

The invention is based on the idea that it is not possible to determine the 3D coordinates of objects within a photo without an external reference point. A laser beam offset from the position of the camera is required. A simplified single laser-camera representation is given in Plate 1. Notice that both the laser and camera directions are parallel to each other, into the paper (y-direction). Plate 2 illustrates the location of a single laser beam scan on a scene. Plate 3 is a close-up of the beam path shown in Plate 2. It illustrates the apparent shift in the laser point of impingement from the viewpoint of the camera, which depends on the distance to the impinged object/scene. By locating the position of the laser on the photo, it is possible to determine the 3D coordinates of the impinged object. This phenomenon was described in US Patent 5,753,931, Paragraph 45 (May 19, 1998).

The present method is discussed below.

3. DETAILED DESCRIPTION

A detailed description of each of the following components of the invention follows:

- Define goal of survey
- Plan survey
- Build system
- Survey Process
- Post process data
- Data Utilization

3.1 SURVEY GOAL

Prior to beginning the survey, the goal or purpose must be established. This may not necessarily be supplied by the client or user. Setting the right goal can reduce survey times and costs because the survey can be carried out with optimal settings. For example, if the goal of a large scale interior survey of a stadium is to allow a computer game to provide a realistic view of the stadium from the viewpoint of players on the field, then it may not be necessary to scan details of each and every seat, from positions above, behind and below each seat, in the entire stadium. On the other hand, if a crime scene is to be transferred to an investigator's computer for further analysis, then the amount of scanning detail required would need to be quite high, especially if the clue being sought is not known prior to scanning.

Note that it is better to acquire too much data than too little. The time and money required to revisit a site can be significant and restrictive. The final product can be filtered to contain only the data requested.

3.2 PLAN SURVEY

After the goal has been determined, Plate 5 is a Specifications Decision Tree that can be used to design a typical survey. Parameters such as scanning resolution, detail, accuracy, time, budget, scale and site access can determine, or will be determined by, the scope of the survey. These factors are inter-related. For example, low budgets may make it undesirable to attain high scanning resolution. Site access restrictions may prevent detail from being achieved in restricted areas. If the goal of the survey is to obtain reconnaissance information, this will affect the specifications selected.

3.2.1 Mode

The first decision that is required is the type of scanning mode, either: Interior or Exterior. Exterior scans can also be called 'object' scans. Interior scans are outward looking, and can include 'object' scans as a sub-set of the overall site scan. Exterior scans are inward looking. For example, scanning all surfaces in a room involves pointing the apparatus away from inside the room. Scanning an object involves directing the scan towards the centre of the object from outside the object. Depictions of both scanning modes are given in Plate 6.

The work can also be carried out at night or in dark rooms using various spectral technologies. For example, infrared light can be used to acquire images without white light.

3.2.2 Scale

The next decision to determine is the overall scale of the scan. These can be broken down into three sub-sets: Large, medium and small (refer to Plate 5). Large-scale scans are done for any area or object that can be "seen" by the system. That is, the laser beams (or spectral sources) must impinge on the surface being scanned and the camera (spectral or regular visual) must be capable of capturing the beams. Medium scale scans are for areas and objects that can be reached but some resolution may need to be sacrificed in select portions of the scene. Small-scale scans include areas and objects that have the highest degree of survey design flexibility given various survey constraints. For example, a bullet found at a crime scene may need to be scanned at a super-high resolution (e.g., must detect minute striations) so that it can be "fired" using a computer, in super-slow-motion, thus allowing precise model-studies.

3.2.3 Data Quality

The quality of measurements can depend on time and budget limitations. Typically, the optimal survey configuration that can achieve the goals set out at the start of the process, in the shortest possible time and at the lowest cost, is the ideal configuration. These can be divided into high, medium and low resolution/accuracy/detail.

Modern digital cameras are often compared in "megapixels" rather than resolution. For example, a three-megapixel camera is better than a one-megapixel camera. Compression methodologies can also be incorporated, although the present invention is designed to handle extremely large streams of data, and so data compression can be used to "fine tune" the operations.

Image stabilization technologies presently exist that allow images to be acquired without degradation of picture quality. This must be used with caution because the calculations for positioning must take into account any "shifts" in picture positioning caused by the stabilizers.

The procedure for carrying out the surveys as defined by the specifications decision tree follows.

3.3 BUILD SYSTEM

In order to carry out the survey, the system must be built and then calibrated. For production mode, it is preferable to build one or two systems, which can be adapted to different survey scales/types, as set out in the survey specifications.

3.3.1 Posts and Rails (One Embodiment)

The ideal system can attain extremely high quality of small objects (e.g., baseball size) and relatively high quality for large-scale surveys such as interior of stadiums. This can be achieved with a rack/post-and-rail system. One embodiment consists of the components mounted on a rail that can be raised using extendable posts. This apparatus can then be transported in any direction using rails that are mounted on the ground and along the beams. Refer to Plate 7 and Plate 8 for generalized depictions.

For large-scale surveys (Plate 7), the scanning apparatus would be mounted on trucks so that greater heights and stability can be achieved. Various leveling and measurement systems will be incorporated into the apparatus to assure accurate measurements. The system can be dismantled for transportation. Note that three cameras can be used pointing in the following directions: forward (into paper), reverse (out of paper) and up (above trucks). The laser clusters can be configured so that at least one pair of clusters, located on both sides of the camera, are captured by each one of the three cameras.

Therefore, if three cameras are used, then six laser clusters need to be mounted to form the entire *Group*. Each camera/laser_cluster sub-group (one camera with two clusters) point in the same parallel direction. The three camera/laser_cluster sub-groups form the *Group*.

The computer system keeps track of the truck positions on the established grid, the location and rotational position of the *Group*, the spacing of individual lasers within each cluster (resolution selected), and the *a*-spacing of the *Group* (distance between camera and lasers). The computers also control the survey speed and rate that photos are recorded.

For small and medium scale surveys the apparatus can be mounted on specifically designed carts. As with the large-scale setup, the computer controls most of the data acquisition system. A

"strobe" lighting system can also be utilized if better lighting conditions are required to distinguish the laser beams from the surface being scanned.

Both trucks and carts can be added in series to allow greater scanning depths by permitting the cluster of lasers to be located further away from the cameras. The setup is then transported along each survey grid line.

Each grid vertex or cell (refer to Plate 4) is expected to represent the location of each apparatus position. The width of the cell is the same, or smaller to allow for overlap, than the *Group's* range of motion along the rails. The assembly moves along the rails to the limit, like a typewriter. It is then "carriage-returned" as the whole cart is moved to the next cell. Higher resolution can be achieved with smaller camera movements and tighter laser clusters. The reverse can be done for lower resolution. The grid vertices can be marked on the ground using spray paint (outdoors) or chalk (indoors).

The vertical telescopic racking system is ideal because it does not obscure the survey areas. The rail, which can allow the *Group* to rotate, is mounted on top of the poles. Guide wires, or other devices, may be used to stabilize the system as required.

3.3.2 Data Acquisition Hardware

The data acquisition system consists of a computer master node controlling a cluster of parallel slave nodes (refer to Plate 9). The physical appearance of such a system is typically a stack of computers mounted on a rack. They may be networked in any number of ways, including, but not limited to cubes, hypercubes (cubes within cubes), meshes and layered webs. An example configuration is illustrated in Plate 9.

Notice that each layer of the web can interact with another computer node. The connection between computers can be altered depending upon the precise requirements. For example, if needed, one computer from each layer can be connected directly to the master node (e.g., Node 1a and 1b connected directly to Master Node). The 1-series of nodes controls each layer. This provides better control of the individual layers from the master. Additional layers can be added, if needed. As well, more or less nodes per layer can be used. Some can be in place as backups in case failures occur in adjacent nodes.

One of the main benefits of having as many nodes connected to each other as possible is to allow "smart" processing of the data. For example, if a node that processes a particular laser acquires data that can not be used by another layer that processes its data (too dark, too much interference, etc.), then the computer should decide whether it is worth stopping the process or continuing.

The only way a decision like this can be made on-the-fly is to allow the interchange of error-checking variables between the nodes at all times. If enough relevant errors accumulate, then the software can calculate a corrective course of action, real time, without manual intervention. For example, the scans may continue if the loss of one laser is not deemed to effect the initial requirements for resolution and if time limitations require that it is more important for the survey proceed.

The benefit of a parallel-processing environment is that extremely large amounts of data can be acquired and stored at extremely high rates. Each computer (node) carried out specific tasks in parallel with each other. The bottleneck in the process will be the mechanical systems used. For example, the speed of the camera (number of photos per second) and the speed by which the system can be moved/rotated along the rail, post and grid.

Notice from Plate 9 (one embodiment, variations possible) that the outermost layer of the cluster consists of the actual sub-systems that carry out the mechanical process. The next layer ("b-series") instructs the individual sub-systems to carry out specific tasks. It also acts as the gateway for the incoming data, which is passed to the next layer ("a-series"). The "a-series" cluster layer stores the data from the adjacent higher level node with time stamps and grid coordinates of the different sub-systems (e.g., distance between laser clusters, distance between individual lasers in clusters, spectral values used for each cluster, *Group* rotation/position, etc). The first layer past the master node ("single-digit series") performs diagnostic services, synchronizes the clocks of all nodes, passes instructions regarding distances, angles, light intensity, etc. to the higher layers. The master node provides user input to all systems (console) and passes instructions to various nodes (i.e., orchestrates the system).

3.3.3 Data Acquisition Software

There are a wide variety of parallel applications development tools, such as PADE (parallel applications development environment), XPVM, as well as code profiling tools such as Tau. A greater number of parallel libraries are becoming more common making parallel programming easier (e.g., PAWS - parallel application workspace, POOMA - parallel object-oriented methods and applications). With the wide spread use of the internet and access to Linux programming expertise from around the world, many more tools are coming on stream as time goes by.

3.3.4 3D Data Acquisition

The apparatus consists primarily of sets of lasers and cameras mounted on a rail. The camera "pinhole" model is used (described in US Patent 4,979,815, Dec.25, 1990). The height of the laser/camera sub-systems is controlled with the telescopic lifting mechanism (Plate 7 and Plate 8). The distance between the individual lasers and between the laser clusters and cameras on the rail is controlled by a rail glide mechanism.

The laser "dot" is always located along the centre horizon of the photos. That is, the laser is projected parallel to the optical axis of the video camera. This is used for scanning objects (manufacturing environment) in US Patent 5,513,276 (Apr.30, 1996), although the mechanics and calculations used to determine the 3D coordinates are very different (e.g., uses "inverse perspective transformation" described in US Patent 4,979,815; therefore, uses a "camera sensor matrix" instead of a standard camera).

3.3.5 Laser "Stripes" Option

A laser stripe, pointing parallel to the camera direction, can also be used, where discrete segments of the stripe are equivalent to a series of laser dots with varying angles above and below the horizon. The laser stripe would also have unique solutions for various laser-camera ***a***-spacings. Using a laser stripe would eliminate the need to rotate the *Group*. However, for such a system to work accurately requires a relatively large set of calibrations and calculations to account for lense distortion, offset viewpoints, etc. Incorporating such as option would be deemed an improvement to the present system if the time required to rotate the *Group* through its normal range of motion, is greater than the time required to obtain accurate laser stripe data.

This invention specifically focuses on a laser-dot methodology, which if necessary to obtain detailed unobscured image information. A discussion of the laser/camera theory for obtaining 3D coordinates of real images follows:

3.3.6 Determining Location of Camera Focal Point and Field of Vision Angle

Images are acquired by a digital camera. The camera can be human-visual or spectral (e.g., infra-red and other remote-sensing frequencies not visible to naked eye). The camera needs to be "calibrated" so that we know what angles each pixel are from the centre of the image. Calibration tests would account for lens distortion and precision of the instrumentation. A different calibration test, designed for a much different system but for similar reasons, has been discussed in US Patent 5,753,931, paragraph 65 (May 19, 1998).

The camera "sees" an image within its field of vision, which is similar to looking through a hollow cone from the narrow end. The total cone angle is referred to as ϕ (refer also to Plate 1, discussed earlier). The image is actually inverted within the camera prior to being transferred to the negative film or recording surface. The focal point may be located somewhere in the centre of the camera, but this may not be necessarily true. Therefore, it is necessary to determine where the focal point of the camera, and the specific lens being used, is. Refer to Plate 10.

To calculate the true focal point, at least two calibration tests should be made: one at distance $M+N$ (N is approximately equal to M) and another at distance N. These distances may depend on the type of lense being used. A narrower angle lense would need larger distances whereas a wide angled lense can use relatively small distances. The two photos would show two different vantage points of the same calibration plate. The shift of a certain point at the outer edge of the photo is O. The value O can be obtained by reading the shift off the calibration plate. The angle $\phi/2$ can be determined with the following equation:

$$\tan(\phi/2) = O/M \qquad \text{(equation 1)}$$

where ***O*** and ***M*** are both directly measurable from the calibration plate.

It is important to use the outermost point useable on the furthest photo, so that the true field of vision can be used. The value ***L*** (and therefore ***N*** which is ***L-M***) can be determined with the following equation:

$$\tan(\phi/2) = P/L \qquad \text{(equation 2)}$$

where ***P*** and ***ϕ/2*** are both known, ***P*** measured directly from calibration plate.

Note that the distances ***O*** and ***P*** can be converted to number of pixels per metre by counting the number of pixels on the photo that covers the various distances measured. These values are need for the laser calculations.

The calibration must be done accurately by holding the plate at right angles to the direction of the camera. (Note: Calibration plates can be walls. The various calibration distances can be achieved by moving the apparatus relative to the "plate"). Perpendicularity can be verified by calculating the angles from all four quadrants around the plate (refer to Plate 11 - Camera Calibration Plate). The angle ***ϕ/2*** should be equal, within tolerance, for all four quadrants.

We can also calibrate the camera angles for each point within the camera frame (refer to Plate 11 – Concentric rings within the image, and Table A for an example of calculations needed to determine the location of the concentric rings). Therefore, every "ring" within the calibrated frame has a unique camera viewpoint angle. Knowing this viewpoint angle is important for calculating the location of the laser reference point described in the next section.

3.3.7 Laser Beams

Although the previous section can determine the viewpoint angle of various portions of any acquired image, it is not possible to determine the 3D coordinates of points within the image without an additional reference point. To do this, an additional constraint is needed – a laser beam.

US Patent 5,778,548 (July 14, 1998) discusses the requirement for trigonometric calculations to determine the 3D position of points on a target object. However, their system uses "rotation matrices" which are not necessary for the present invention, because the present invention is fully parallel, with the same camera axis and laser directions.

Each laser beam should be conical-shaped so that the further away from the apparatus, the wider it is. Therefore, it must be of increased energy for objects located at greater distances. The angle of the cone should be chosen to match the desired resolution. That is, features located further away may not necessarily require the same resolution as objects located near by. If high resolution is required for objects located further away, a smaller cone is required, and/or the apparatus should be moved closer to the target.

The method involves utilizing a laser located a fixed distance *a* from the camera. Refer to Plate 12 – Laser Calculations.

The laser will always point in the same parallel direction as the camera direction, with $\theta_y = 0$ degrees (refer to Plate 1). Note that distance a can be varied depending upon the site and system characteristics (discussed further in Laser Cluster Configuration sub-section).

If we take the calibration plate, we can ensure that the laser and camera directions are in the same plane and the focal point of camera and hinge point of the laser or at the same y-coordinate. The laser point would be located exactly in the vertical centre of quadrant *II*, for the example shown in Plate 12 (refer also to Plate 11). Notice that if calibrating a second laser, it would be located in the vertical centre of quadrant *IV*. It is important for the camera to be properly located and directed with respect to the calibration plates, as discussed earlier, and that the centre of the photo is identifiable, by pixel coordinates.

Notice also that as the calibration plate moves towards or away from the camera in the same direction as the camera and laser directions (y-direction using coordinate system illustrated in Plate 1), the laser points at exactly the same spot on the calibration plate (a metres from centre-line). However, the camera "sees" the laser point moving towards the edge of the photo as the calibration plate moves towards the camera/laser apparatus, as shown on Plate 12. If the direction of the laser is fixed at a different angle from the horizontal (i.e., if laser doesn't point in same direction as camera), then the line would seem to have an angle towards the centre line of the photo. As the angle increases, or decreases, the absolute value of the angle to the horizontal increases. This "migration" of the laser beam from the vertical centre can be used to check and calibrate the system.

As can be seen from Plate 12, each angle and distance from the camera will have a unique solution.

Note that the calibration "plates" illustrated in the present invention are flat. A convex plate may seem more appropriate, given the nature of the camera lens and changing angle of incidence. However, this is not necessary due to the calibrations illustrated on Plate 11 and Table A.

3.3.8 Determining 3D Coordinates: Laser Pointed in Same Direction as Camera, Offset Distance " a"

From Plate 12, the goal is to determine the viewpoint angle, ψ, from the calibration plate (refer to Plate 10). Two pixel counts are required, the first being the number of pixels in the photo between the centre line of the photo and the position of the laser (***a*** expressed in number of pixels). The second count required is the distance ***P*** expressed in number of pixels. The ratio of ***a*** (in pixel counts) over ***P*** (in pixel counts) is a number that can be matched to the normalized column calculated in Table A. The normalized column makes it possible to directly link laser positions within the image to camera viewpoint angles.

The ratio of ***a/P*** from the acquired image is located in the "distance normalized" column of Table A. The corresponding "camera viewpoint angle" is the viewpoint angle ψ. Note that in this example, $\phi/2$ is 29 degrees. The table would be recalculated depending on the true range of vision for the selected camera and lens. US Patent 4,979,815, Dec.25,1990 discusses and proves the "invariance of cross-ratio under central projection". This theory shows the validity of this calculation.

Now that the camera viewpoint angle for the laser impingement point is known, it is a trivial matter to calculate the distance along the y-axis (refer to Plate 1) between the camera focal point and the impingement point:

$$\mathrm{Tan}(\psi)=a/L$$

therefore,

$$L= a\,/\,\mathrm{Tan}(\psi) \qquad \text{(equation 3)}$$

where ***a*** and ψ are known, ***L*** can be expressed in metres.

The computer system records this value with the corresponding x and z coordinates, which are equal to the camera focal point location. Thus, the 3D coordinates have been defined.

3.3.9 Group Angle Varies Above and Below Horizon, Directed in Parallel YZ Plane

As mentioned earlier, it is more simple and accurate to rotate the entire laser/camera *Group* than to use a rigid *Group* with laser stripes. This is illustrated in Plate 13.

The *Group* rotation angle is θ_y. Once the point of impingement (refer to Plate 12) is known with respect to the rotated *Group*, it can be projected to the main grid system. The x-coordinate is unchanged because the *Group* rotates about the x-axis. However, the y- and z-coordinates will change.

To calculate the amount that the x and y coordinates need to shift so that they are referenced to the base coordinates, the following calculations are made (refer to Plate 13):

$$\mathrm{Sin}(\theta y) = \boldsymbol{deltaZ/L}$$

therefore,

$$\boldsymbol{deltaZ} = \boldsymbol{L}\mathrm{Sin}(\theta y) \qquad \text{(equation 4)}$$

and

$$\mathrm{Tan}(\theta y) = \boldsymbol{deltaZ/C}$$

therefore,

$$\boldsymbol{C} = (\boldsymbol{deltaZ})\mathrm{Tan}(\theta y) \qquad \text{(equation 5)}$$

Which means,

$$\boldsymbol{deltaY} = \boldsymbol{L} - \boldsymbol{C} \qquad \text{(equation 6)}$$

By applying the shifts calculated in equation 4 and equation 6, it is possible to reproject the scanned image to the main coordinate system.

3.3.10 Movement of Laser Across Photo Frame

The laser point of impingement moves across the photo from the outside towards the centre. For the parallel camera/laser system, the path is along the center horizontal axis. Plate 14 is an illustration of this concept. Table B contains calculated values for an example [($\phi/2$)=29 degrees, a=5m] of the predicted location of the point of impingement on the photo for equal increments of increasing distance between the camera and point of impingement.

The calculations are as follows:

$$\tan(\phi/2) = \frac{(a+b)}{L} \qquad \text{(equation 7)}$$

which is equivalent to

$$b = L\tan(\phi/2) - a \qquad \text{(equation 8)}$$

The ratio of *a/(a+b)* is then calculated. Notice that when ***b*** becomes very large, the ratio approaches zero. This ratio can then be multiplied by the total number of pixels that span the photo from the centre line to the edge of the useable image. A graph of this is also illustrated in Table A and further illustrated in Plate 14. The "power series 4" curve is an exaggeration of

the movement which makes it easier to define the distance to target at which a new *a* spacing should be selected.

That is, the conclusion drawn from these calculations and graphs is that it is more difficult to differentiate different values of distance when the distance *a* between the camera and laser becomes very small compared to the total distance photographed *(a+b)*. For increasing values of *L* (increased distance from the laser/camera apparatus to the point of impingement), the rate of change for the number of pixels crossed by the beam decreases. This means that a relatively large shift in *L* will begin to have a relatively small shift across the photo and therefore the calculated distance to the point of impingement will become more inaccurate.

This problem has been addressed, as discussed next.

3.3.11 Laser Cluster Configuration

The distance between the laser clusters and the camera centre-line depends on the distance to the target. As illustrated in Plate 14 and Table B, the *a*-spacing between the camera and lasers should increase for greater distances to the target being scanned. An illustration of this is given in Plate 15. A rule of thumb is to have the lasers limit scans to regions that are greater than halfway from the centre of the photo. From Table B, this position if found by locating the value for the ratio $a/(a+b)$=0.5. The corresponding *L* value is at 9 metres (refer to Plate 14).

The goal is to have the laser cluster points of contact located between the range limit lines (scan range, Plate 15) for the entire movement of the apparatus along the x-direction (see Plate 1 for coordinate system). If the laser impinges on a surface outside the scanning range, it is necessary to change the *a* spacing to a new range. The laser moves across the photo at the greatest rate for changes in distance to target when it is nearer to the edge of the photo (as illustrated in Plate 14). Therefore, greater accuracy of calculations of 3D coordinates is possible.

As many lasers can be used as possible. Each laser has a unique spectral signature or "colour" that can be recognized by the post-processing computers. A method for recognizing the various spectral signatures is described in US Patent 5,753,931. The spacing between lasers is the related to the resolution desired. That is, if 1-cm detail is required, then the lasers should be spaced no more than 1 cm apart. If 1-metre accuracy is sufficient, for large structures located far from the apparatus (e.g., buildings), then the lasers would be spaced less than 1 m apart on a large rail system, as illustrated in Plate 7.

Although the survey resolution is also controlled by the spacing of the individual lasers within the laser cluster it is also controlled by the incremental "steps" the system is shifted along the rail system and along the survey grid.

Notice in Plate 15 that Range 1 uses a small *a*-spacing, whereas Range 3, for further targets, has a larger *a*-spacing. The computer can automatically adjust the *a*-spacing if the impingement area is beyond a predetermined range. If high accuracy is required, more range-windows need to be programmed - the cost being a slowing of the overall survey.

3.4 SURVEY PROCESS

Automation technologies can be incorporated into the system to achieve high-production mode surveys. For example, repetitive movements of the apparatus along the rails, movements along the grid, etc. can be automated.

Once the goals have been determined, the survey planned, and system built, it is time to acquire the data. There are three parts to data acquisition:

1) Survey Grid
2) Mechanical Apparatus Positioning
3) Systems Control

3.4.1 Grid Setup

This is the most important part of data acquisition. An accurate, well-set grid will maintain the overall quality of the survey. It also allows the survey to be carried out in a structured and efficient manner. A poorly laid grid will destroy the integrity of the data, regardless of how well the remainder of the survey is carried out.

Plate 4 is similar to Plate 1, with the addition of the survey grid. Notice that the grid only needs to be laid out on the floor, controlling the x and y directions. The z-direction is controlled by the apparatus adjustable lifting mechanism (e.g., telescopic posts). Note also that "lines" need not be drawn, only the intersection of the x and y direction points would be marked with "dots".

A grid reference origin must be selected. For example, in Plate 4, the origin is the corner of the building. The positive x and y directions can be easterly and northerly, whereas negative coordinate values represent westerly and southerly directions, for example. Up represents positive z values, below the reference datum plane represents negative z-values.

The grid should be established in all accessible locations, depending on the resolution and detail of information required. A smaller apparatus may be necessary to get behind the table, for example, if information in this area is deemed important. Notice that the grid was not laid-out on top of the table, in the example given in Plate 4. The reason being that pre-measured reference guides can be extended to known reference points where needed.

Sub-grids can also be established in areas that require higher detail scanning. For example, if the mechanism needs to be located on top of the table so that greater detail can be obtained for the "flower pot", then the apparatus would be referenced to the grid laid out on the floor using plumb-bobs and measuring tapes. The computer software would allow input for these

parameters so that the acquired data are referenced to the main grid.

For small-scale surveys, the grid density could be as tight as every few centimetres. For medium scale surveys, the density could increase to half-metre intervals. For large-scale surveys, the grid could be established on parallel base lines and tie lines spaced, say 40 metres apart with reference points marked along the base and tie-lines at 2-metre intervals. Fluorescent orange spray paint or chalk can be used to mark the grid.

Note that the apparatus need not traverse the entire grid. The goal is to acquire data that can be used to display the various images with 3D coordinates. The detailed grid layout gives the operator greater flexibility for deciding, on the fly, where greater detail is required, and areas where the apparatus does not need to traverse. For example, wide-open rooms need only be surveyed along the inside perimeter.

3.4.2 Mechanical Apparatus Positioning

The apparatus can begin scanning from any location on the grid. The important thing is that the x, y and z-coordinates are known and recorded for every position of the apparatus. Otherwise, it will not be possible to reference the 3D position of the scanned surface to the main grid.

There are three movements involved in the scanning process. The primary movement involves the movement of the entire apparatus over the main or sub-grids. The secondary movements consist of four types of motions:

1) Type I involves changes in the *a*-spacing for each laser and camera pair.
2) Type II involves changes in separation between the individual lasers for each laser cluster.
3) Type III involves the vertical movement of the laser and camera groups (*Group*) along the telescopic beams in the z-direction.
4) Type IV involves the shift of the laser and camera groups (*Group*) along the horizontal beam (refer to Plate 7 and Plate 8).

The primary movement is the setup and apparatus rooting. The secondary movements position the apparatus for detailed data acquisition. To start the survey, the apparatus is setup and positioned at a grid reference point [e.g., (5 metre, 6 metre, 0 metre) grid coordinate]. This is the primary movement. Once the apparatus is positioned, data can be acquired.

The Type I and Type II positions are set initially. Once these are set, either the Type III or Type IV movement can commence. Changes in Type I and Type II settings can be made as needed during each scan. The computer keeps track of these parameters.

3.4.3 Systems Control

As illustrated in Plate 9, the computer can control the mechanical systems as well as the data acquisition and storage mediums. This is achieved with parallel processing software, which can be written in Linux. As discussed earlier, all data is stored with time stamps, and all computer nodes are synchronized. Additional cross-referencing data are also recorded for each parameter to allow more reliable post processing. For example, semi-static settings such as the Type I and Type II movements can be recorded with various data as required.

As the data streams are acquired, they can initially be held in RAM/cache memory, which saves time. From here they can be stored on some other more permanent media (e.g., hard disk). Data are stored in the "a-series" (see Plate 9) and can be backed-up amongst each other "a-series" or [backup] nodes. For example, a copy of node 8a can be made on 7a, and vice-versa. This is important because the data can have significant monetary cost of acquisition.

3.5 POST PROCESS DATA

The data are transferred from the "a-series" nodes to an office-based post processing computer cluster. The cluster can be similarly designed as a series of layered nodes, controlled by a master node. Each node has a specific or redundant function. The goal of the software is to compile all systems data for each sub-system (e.g., *a*-spacings, main grid coordinates, sub-grid coordinates, apparatus height, photographic images, laser frequencies, etc.)

All data are maintained in a data base that allows fast correlation. For example, certain relational databases can be established so that specific parameters can be accessed by the computer rapidly. Different nodes can store different parameters, which can be cross-referenced.

Each stored computerized image must be "re-scanned" by the computer. US Patent 5,753,931 (May 19, 1998) provides a detailed description for detecting portions of images that represent laser impingement regions. US Patent 5,513,276 (Apr.30, 1996) uses "moment techniques" to find the centroid of the cluster of pixels as a single digitized point or pixel. US Patent 5,675,407 (Oct.7, 1997) discusses a method for detecting various wavelength spectrum, although it does not use laser beams, instead, it uses diffracted visible white light, UV, or IR light regions.

The 3D calculations are computed, as described earlier, and a matrix of solutions can be created that has the (x,y,z) position and pixel value of the image (e.g., 8 bit Red, Green, Blue sub-matrix). These matrices of solutions can be stored in various formats so that access by other applications is rapid. For example, the matrices can be broken down into low resolution blocks, medium resolution blocks, and high-resolution sectors.

Moving-average pixel values can also be incorporated into the database. For example, images that are located at large distances from the observer can be represented by the average value (e.g., RGB) of many pixels within a pixel-grouping radius. The greater the number of computer nodes that can be accessed in parallel, the greater the ability to store the data in the various formats.
The 3D positioning and image data exist in various databases on the office-computer cluster. The format required for each application may vary. If it is known that only certain ranges of

motion are required, then only certain types of data need to be accessed. Because it is likely that more data were acquired than necessary, some data screening/filtering can be done. For example, a baseball stadium can be divided up into a number of 3D sectors that require various levels of resolution and detail. These sectors are analyzed, processed and stored based on the data requirements. A high detail sector would have more data stored, whereas a low detail or priority sector would contain more averaged data.

3.6 DATA UTILIZATION

The data would be converted to the format required by the client. Data compression technologies may be applied to allow easier data transfer across various media and storage devices.

4. PRIOR ART

Visual information that can be acquired and stored in three dimensions is not a unique idea. There are a number of patents that claim to acquire and store three-dimensional (3D) data. Note that "present invention" refers to the invention being proposed.

US Patent 5,753,931 (May 19, 1998) describes a method of acquiring surface contour information. It uses 66 parallel laser "stripes" and is primarily designed for contouring objects such as the underside of a human foot. The technique described appears satisfactory for scanning objects of finite size (e.g., people for fitting clothes), but is not sufficient for scanning large areas or objects. For example, the cameras and laser directions appear to cross, whereas in the present invention it is crucial that they remain pointed along the same parallel plane and in the same direction. US Patent 5,753,931 appears to emphasize the need to obtain data rapidly due to the nature of the target (e.g., people), thus necessitating the use of a line-array of lasers and multiple cameras acquiring all of the data within seconds (e.g., snapshot), with no moving parts. The present invention is designed for stationary objects only, and therefore has no requirement for instantaneous and total measurements within seconds. The present invention involves many moving parts. US Patent 5,753,931 uses mirrors and diffraction gratings – not needed for the present invention.

US Patent 5,778,548 (July 14, 1998) describes a method for obtaining "non-contacting" 3D measurements of objects. The device, which is a movable gantry machine, is relatively large compared to the object that needs to be scanned. Unlike the present invention, it requires a "prismatic gauge" for calibration (lines 57 onwards). The gauge is defined by 26 flat lateral walls and 8 triangular walls, with holes in it. This patent goes on to describe the calibration and measurement procedures, which are nothing like the present invention's setup or process.

US Patent 5,848,188 (December 8, 1998) describes a laser-stripe shape-measuring device, for objects. It is dissimilar from the present invention in that the laser is a stripe and the camera and laser are not parallel and not pointing in the same parallel direction. A rotating mirror is used to move the laser across the object being scanned. In the present invention, the laser direction is fixed with respect to the apparatus. US Patent 5,848,188 appears to record only the dark and

bright states using bits 0 to 7 (gray code). It does not appear concerned with duplicating colour, textures, etc., which the present system does.

US Patent 5,870,220 (February 9, 1999) uses a stripe generator. It also uses non-parallel laser and camera directions. It is designed to be rapid for scanning objects that can not easily remain motionless. It appears limited to scanning finite sized objects.

US Patent 5,889,582 (March 30, 1999) does not provide a systematic or grid-directed scan of objects, instead, it claims to be "intelligent" and only scans "areas of interest". Like the previous inventions, the laser and camera directions are not parallel. It also uses a "laser range scanner" which requires the beam to be reflected back to the range scanner and thereby indicating the range to the object. The present invention does not use "laser range scanners". It is also only concerned with generating a computer model of the object. Like the previous inventions, it is not designed for scanning large objects or areas.

US Patent 5,973,788 (October 26, 1999) uses one or more "range finders". The present invention does not use "range finders". The "range finder" consists of a light pen with reflectors. Range finders require retroreflective targets or reflective tape – clearly this is infeasible for the requirements of the present invention, and fundamentally different.

US Patent 6,094,269 (July 25, 2000) consists of lasers and camera angles that are non-parallel (can intersect each other at a scanning region). It also uses laser stripes. The object being scanned is located in the middle of the machine. Only one moving axis is used, therefore, it is necessary to rotate or move the object being scanned, to obtain different cross-sections. It uses an array of detector elements – which is fundamentally different from the present invention. It appears to focus on obtaining cross-section information of objects in a manufacturing or quality control environment.

US Patent 5,675,407 (October 7, 1997) uses a known spatially distributed wavelength spectrum to acquire 3D information about scanned objects. It requires equipment that can detect and differentiate different wavelengths. Because it is fundamentally designed around the principle of refracted light, the various wavelengths will impinge the object surface at an angle to the camera direction, which is fundamentally different from the present invention, which requires that lasers, which can have different wavelengths, point in the same parallel direction.

US Patent 5,513,276 (April 30, 1996) uses parallel laser and camera directions, but there are other significant differences. It uses complex matrix processing techniques whereas the present invention takes advantage of parallel computer processing and storing, thus greatly simplifying the process. It requires that the lasers (~670 nm) be actuated by various means so that they can be discriminated. The present invention has no need for this because various wavelength lasers can be used and discriminated from each other during post processing. The present invention can use a standard digital camera, not a "sensor matrix". This invention is designed primarily for manufacturing items. It produces a "model" of the scanned object, not a "real" depiction, like the present invention. The present invention can be fully automated whereas this invention requires major user control. The present invention consists of moving the entire apparatus over the grid at regular intervals, thus eliminating "occlusion" problems, identified in this invention.

US Patent 5,497,188 (March 5, 1996) uses a "range finder", unlike the present invention. It also

has the ability to use the same lens for both the laser beam and optical camera – this is not possible with the present invention and displays how radically different the "range finder" device is. This patent is quite vague and provides very little detail on how 3D images located, etc.

US Patent 5,424,835 (June 13, 1995) uses a lamellar plane laser beam with various optical compensation mechanisms (e.g., "parallel mirrors" phenomenon to widen the laser stripe). It is designed and limited to scanning objects of finite scale. It too, is difficult to determine whether it is described and capable of determining 3D coordinates of a scanned object.

US Patent 5,216,476 (June 1, 1993) is a stereoscopic system – and therefore very dissimilar from the present invention.

US Patent 5,193,120 (March 9, 1993) is designed for manufacturing and processing environments. It uses parallel laser stripes, which are at an angle to the camera direction – unlike the parallel present system. This invention appears to be very similar to previously described patents.

US Patent 4,979,815 (December 25, 1990) is only useful for scanning small objects or areas. Because it uses laser stripes, it requires a calibration for the assembly with different settings. The present invention is designed as a "dot" system to solve camera "occlusion" limitations, which are not deemed critical for US Patent 4,979,815 because the size of the objects being inspected are relatively small compared to the it is readily easy to move the apparatus around the object, for example. The camera axis and laser directions are not parallel for this system.

US Patent 4,948,258 (August 14, 1990) uses a holographic grating structure to emit divergent light. Therefore, the light and camera directions are not parallel. This system is a relatively crude method for digitizing objects because control of resolution is dependant on the ability to detect the various divergent light beams impinging the object or area. It is more concerned with determining the range to an object or feature.

US Patent 4,777,501 (October 11, 1988) is designed only to allow a means for focusing a camera underwater or in some other harsh environment.

US Patent 4,316,670 (February 23, 1982) & US Patent 4,498,770 (February 12, 1985) is designed for object scans (e.g., manufacturing environment). It is designed for object surface contour measurements. It uses three laser transmitters, oriented at various angles to the camera axis – unlike the present invention which is a fully parallel system.

US Patent 4,294,544 (October 13, 1981) is designed for "autoreplication" of objects in manufacturing settings. It uses a rectilinear array of bright beams. It uses a fairly complex series of equations, algorithms and physical properties to calculate various parameters. The laser and camera axes are non-parallel.

APPENDIX A – Plates

APPENDIX B – Tables

TABLE A **- Camera Calibration Plate "Template" Calculations**

Example:

=29 degrees :angle (Phi/2)
=1 metre :distance to plate, ***L***

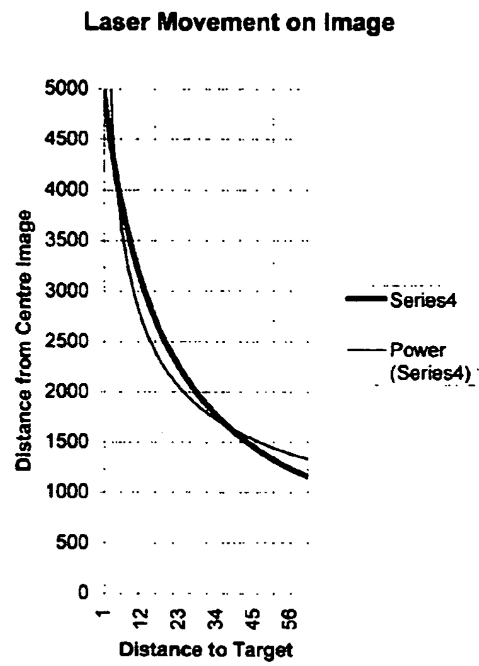
	=tan(viewpoint)x 1m	
camera viewpoint angle (deg.)	***distance centre-line to viewpoint***	***distance normalized, Phi/2=1***
1.0000	0.0175	0.0315
2.0000	0.0349	0.0630
3.0000	0.0524	0.0945
4.0000	0.0699	0.1262
5.0000	0.0875	0.1578
6.0000	0.1051	0.1896
7.0000	0.1228	0.2215
8.0000	0.1405	0.2535
9.0000	0.1584	0.2857
10.0000	0.1763	0.3181
11.0000	0.1944	0.3507
12.0000	0.2126	0.3835
13.0000	0.2309	0.4165
14.0000	0.2493	0.4498
15.0000	0.2679	0.4834
16.0000	0.2867	0.5173
17.0000	0.3057	0.5516
18.0000	0.3249	0.5862
19.0000	0.3443	0.6212
20.0000	0.3640	0.6566
21.0000	0.3839	0.6925
22.0000	0.4040	0.7289
23.0000	0.4245	0.7658
24.0000	0.4452	0.8032
25.0000	0.4663	0.8412
26.0000	0.4877	0.8799
27.0000	0.5095	0.9192
28.0000	0.5317	0.9592
29.0000	0.5543	1.0000

TABLE B - Laser Position on photo as *L* varies

Example:
refer to Plate 12 & Plate 14

29	*:angle (Phi/2)*	*degrees*
0.5543	*:tan(Phi/2)*	*units*
5	*:a*	*metres*
5000	*:total pixel units CL to edge*	

L *metres*	(equation 8) *distance* *b* *metres*	*ratio* *a/(a+b)* *units*	*# pixels* *from* *CL*
0.0000	0.0000	1.0000	5000
0.5000	0.2772	0.9475	4737
1.0000	0.5543	0.9002	4501
1.5000	0.8315	0.8574	4287
2.0000	1.1086	0.8185	4093
2.5000	1.3858	0.7830	3915
3.0000	1.6629	0.7504	3752
3.5000	1.9401	0.7205	3602
4.0000	2.2172	0.6928	3464
4.5000	2.4944	0.6672	3336
5.0000	2.7715	0.6434	3217
5.5000	3.0487	0.6212	3106
6.0000	3.3259	0.6005	3003
6.5000	3.6030	0.5812	2906
7.0000	3.8802	0.5631	2815
7.5000	4.1573	0.5460	2730
8.0000	4.4345	0.5300	2650
8.5000	4.7116	0.5148	2574
9.0000	***4.9888***	***0.5006***	***2503***
9.5000	5.2659	0.4870	2435
10.0000	5.5431	0.4742	2371
10.5000	5.8202	0.4621	2310
11.0000	6.0974	0.4506	2253
11.5000	6.3746	0.4396	2198
12.0000	6.6517	0.4291	2146
12.5000	6.9289	0.4192	2096
13.0000	7.2060	0.4096	2048
13.5000	7.4832	0.4005	2003
14.0000	7.7603	0.3918	1959
14.5000	8.0375	0.3835	1918
15.0000	8.3146	0.3755	1878
15.5000	8.5918	0.3679	1839
16.0000	8.8689	0.3605	1803
16.5000	9.1461	0.3535	1767
17.0000	9.4233	0.3467	1733
17.5000	9.7004	0.3401	1701
18.0000	9.9776	0.3338	1669
18.5000	10.2547	0.3278	1639
19.0000	10.5319	0.3219	1610
19.5000	10.8090	0.3163	1581
20.0000	11.0862	0.3108	1554
20.5000	11.3633	0.3056	1528
21.0000	11.6405	0.3005	1502
21.5000	11.9176	0.2955	1478
22.0000	12.1948	0.2908	1454
22.5000	12.4720	0.2862	1431
23.0000	12.7491	0.2817	1409
23.5000	13.0263	0.2774	1387
24.0000	13.3034	0.2732	1366
24.5000	13.5806	0.2691	1345
25.0000	13.8577	0.2651	1326
25.5000	14.1349	0.2613	1307
26.0000	14.4120	0.2576	1288
26.5000	14.6892	0.2539	1270
27.0000	14.9663	0.2504	1252
27.5000	15.2435	0.2470	1235
28.0000	15.5207	0.2437	1218
28.5000	15.7978	0.2404	1202
29.0000	16.0750	0.2372	1186
29.5000	16.3521	0.2342	1171
30.0000	16.6293	0.2312	1156



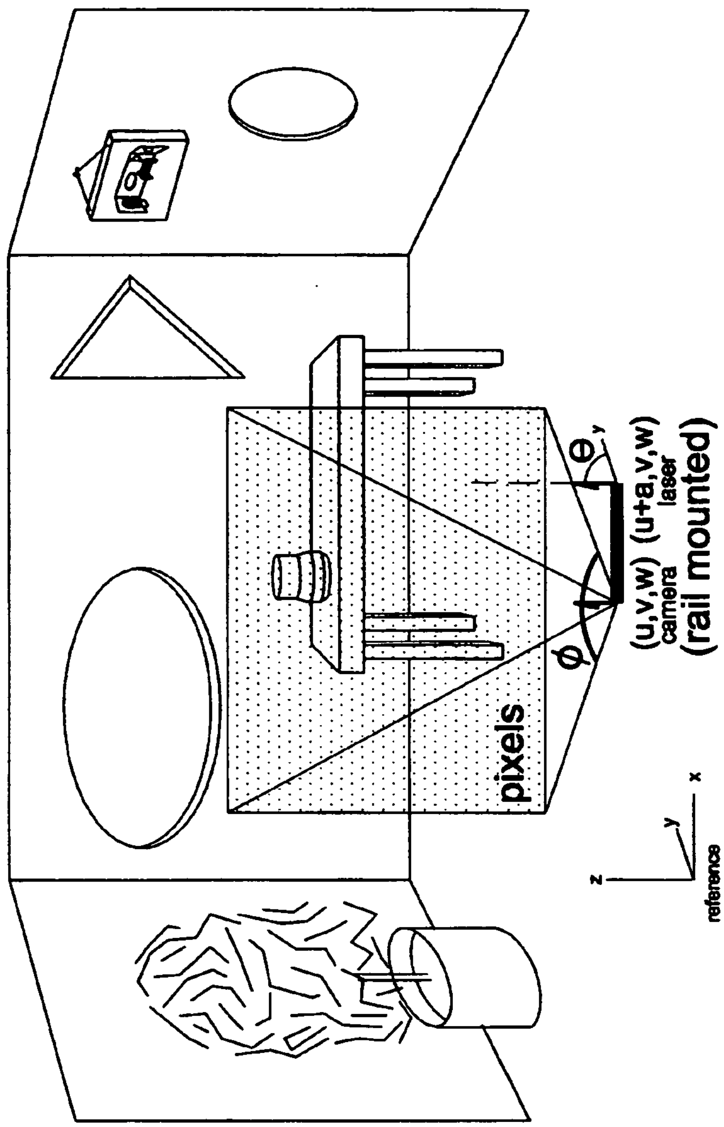


Plate 1 - Simplified Configuration

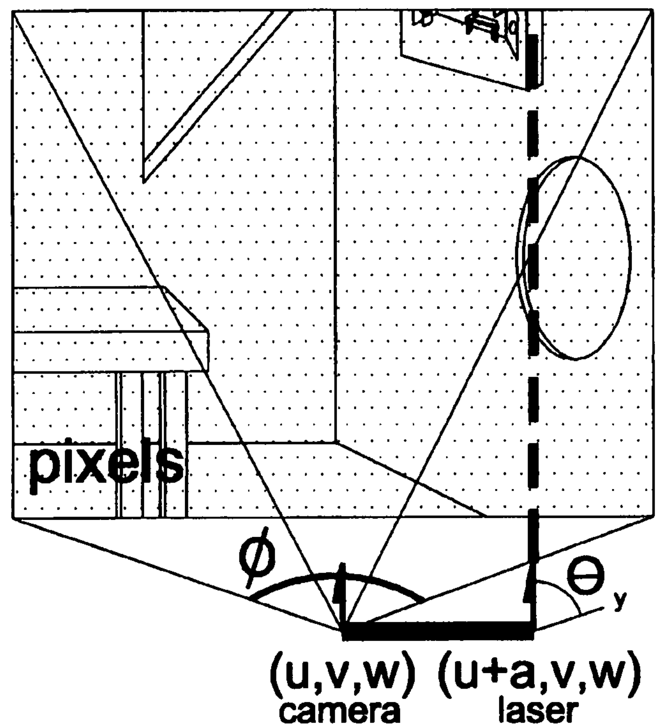


Plate 2 - Coverage of Laser Path

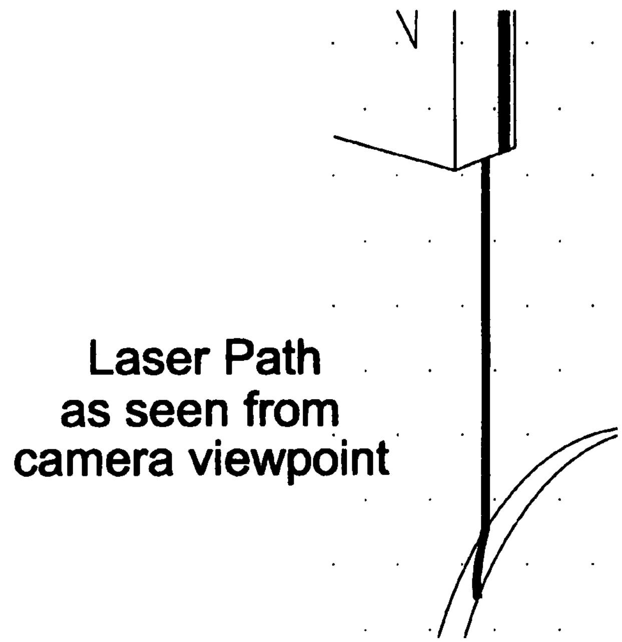


Plate 3 - Apparent Shift of Laser Position from Camera Viewpoint

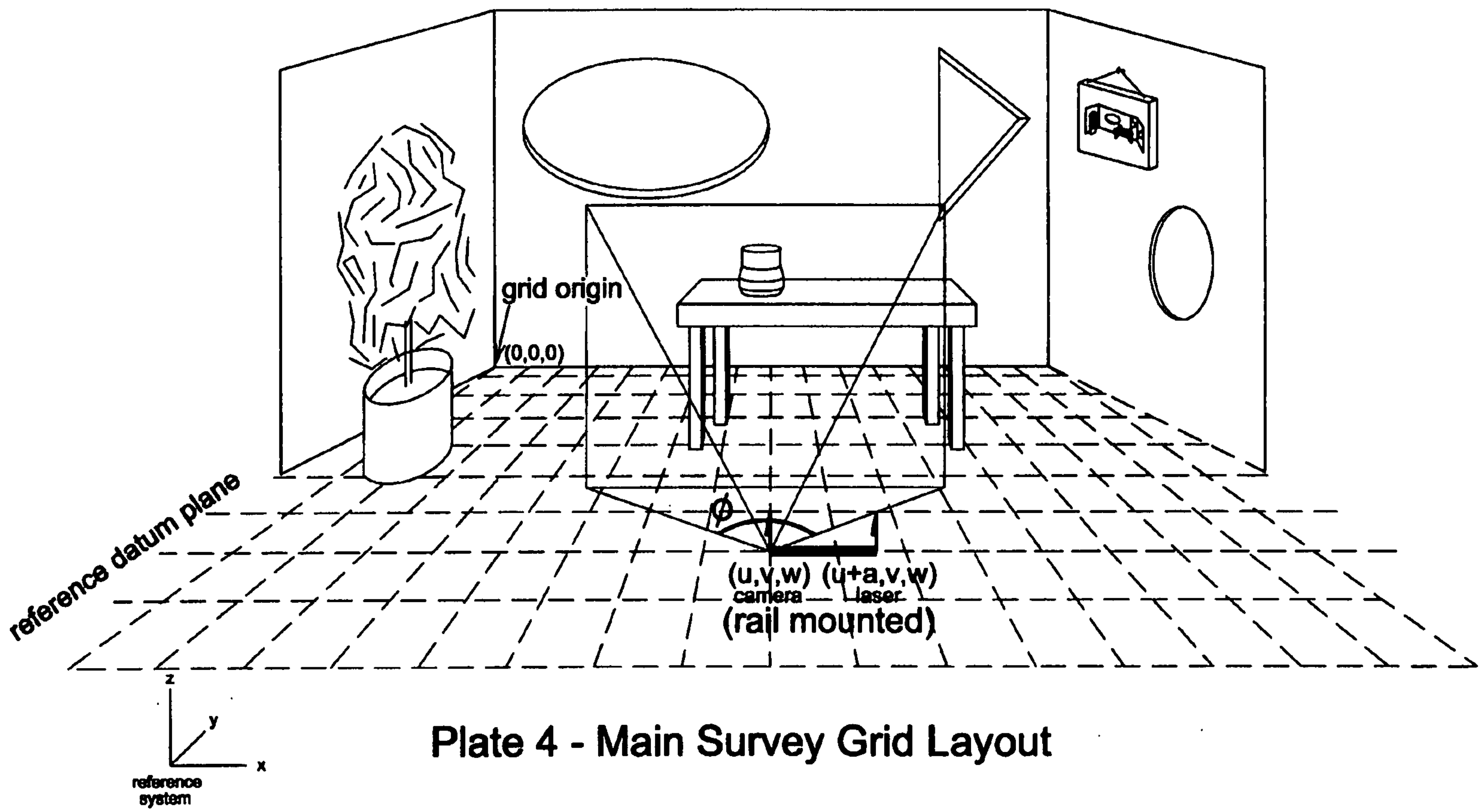


Plate 4 - Main Survey Grid Layout

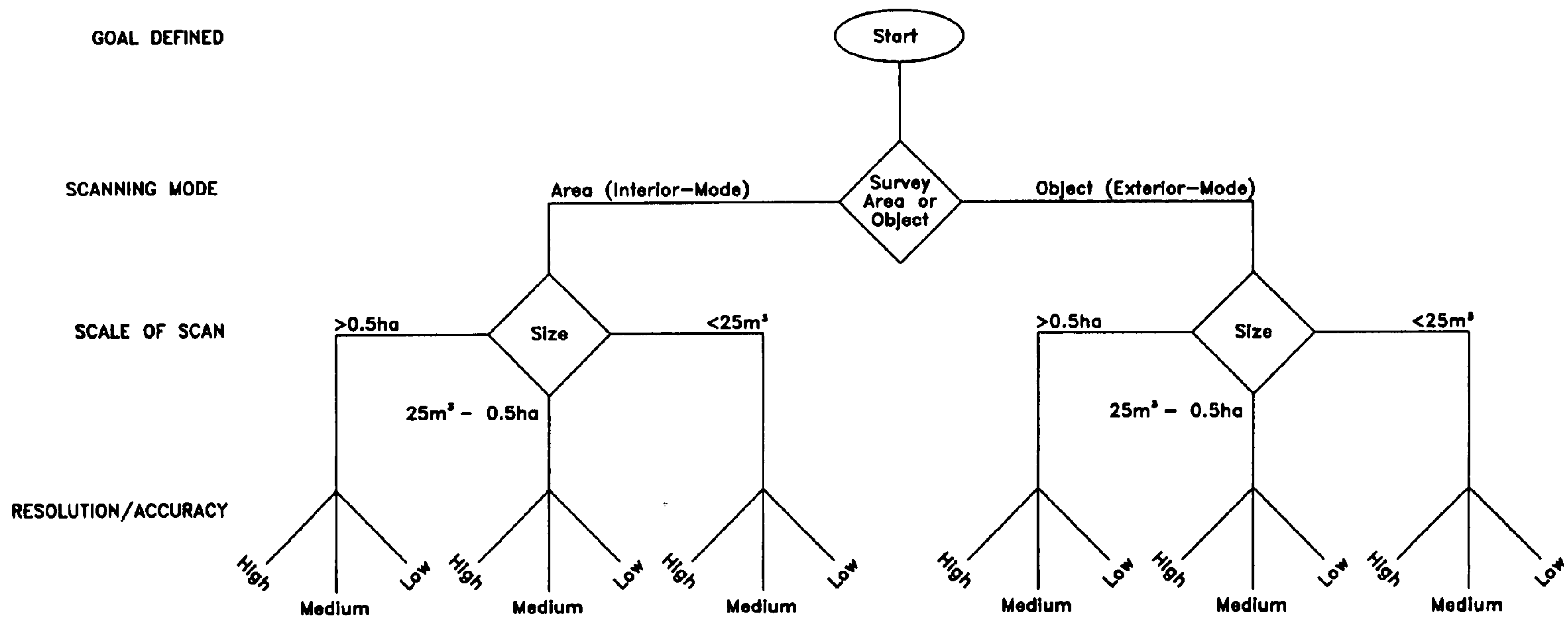
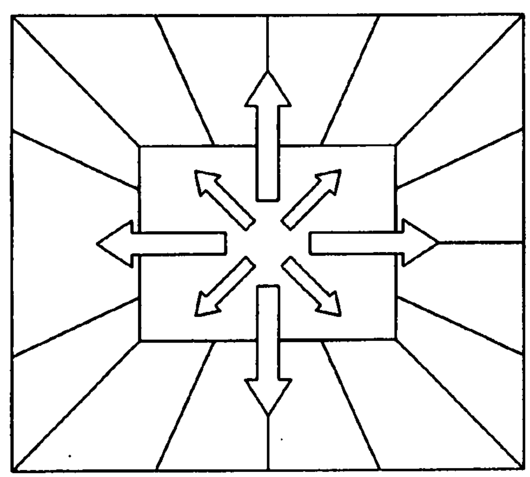


Plate 5 - Specifications Decision Tree

INTERIOR SCAN



EXTERIOR SCAN

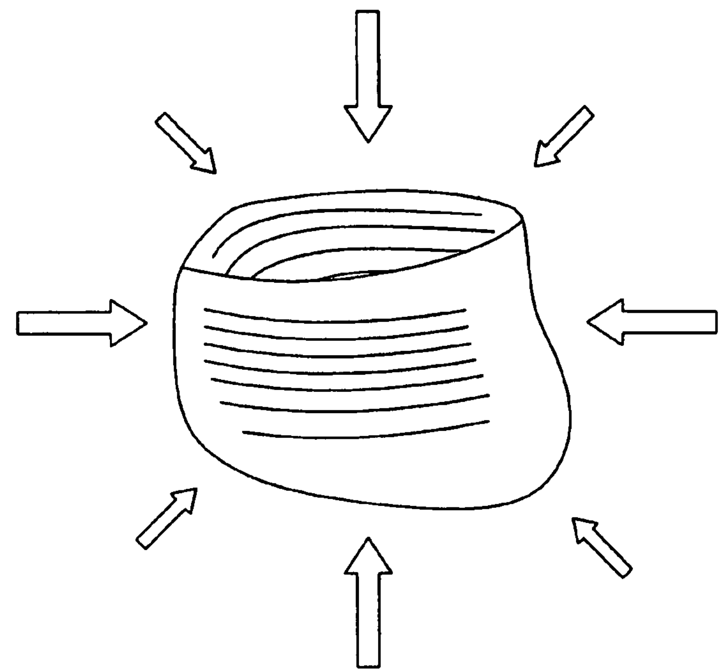


Plate 6 – Scanning Modes

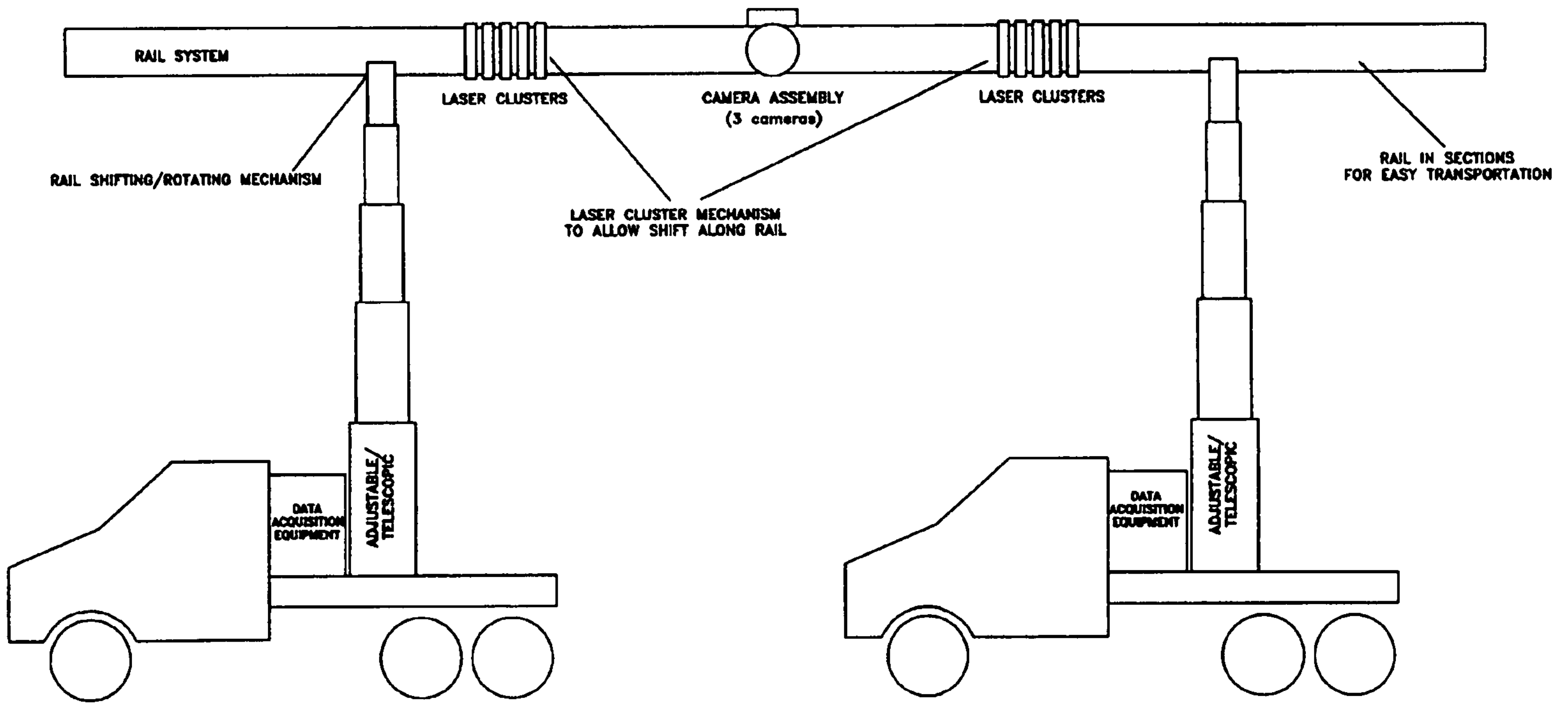


Plate 7 – Large Scale Surveys

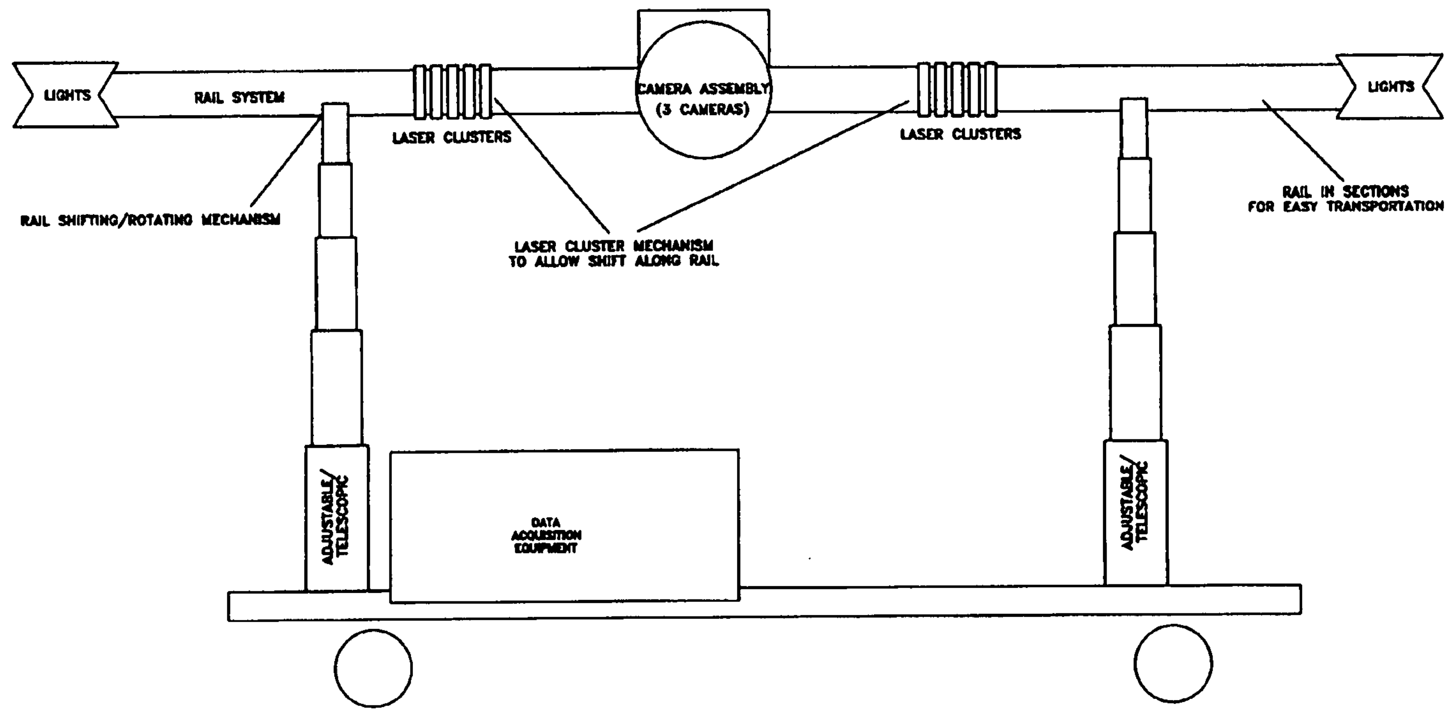
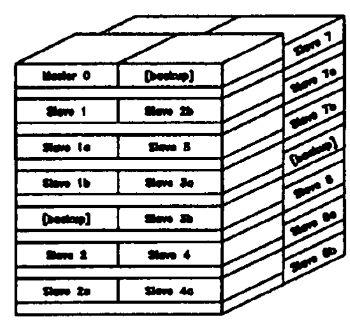


Plate 8 – Small and Medium Scale Surveys

PHYSICAL STACK



NODE CONNECTIONS

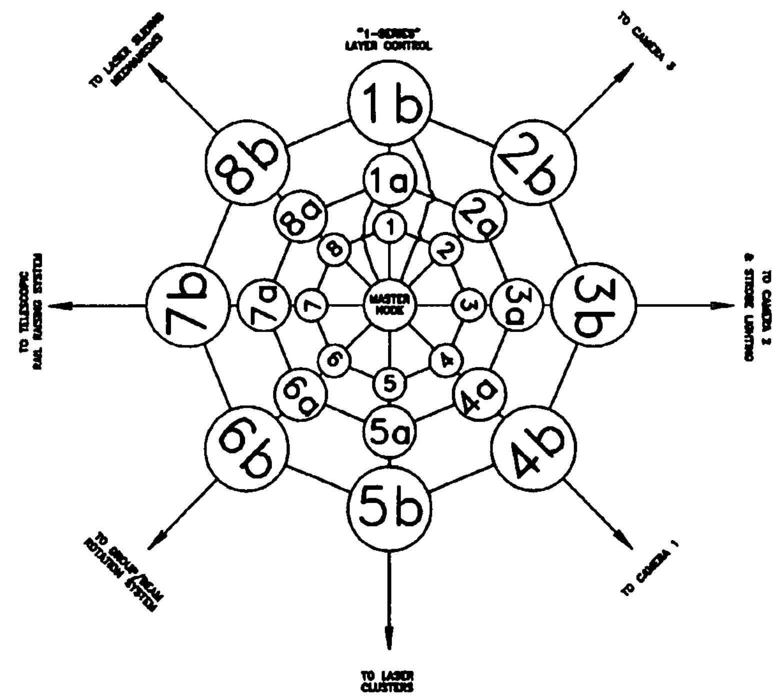


Plate 9 – Parallel Computer Cluster – DATA ACQUISITION

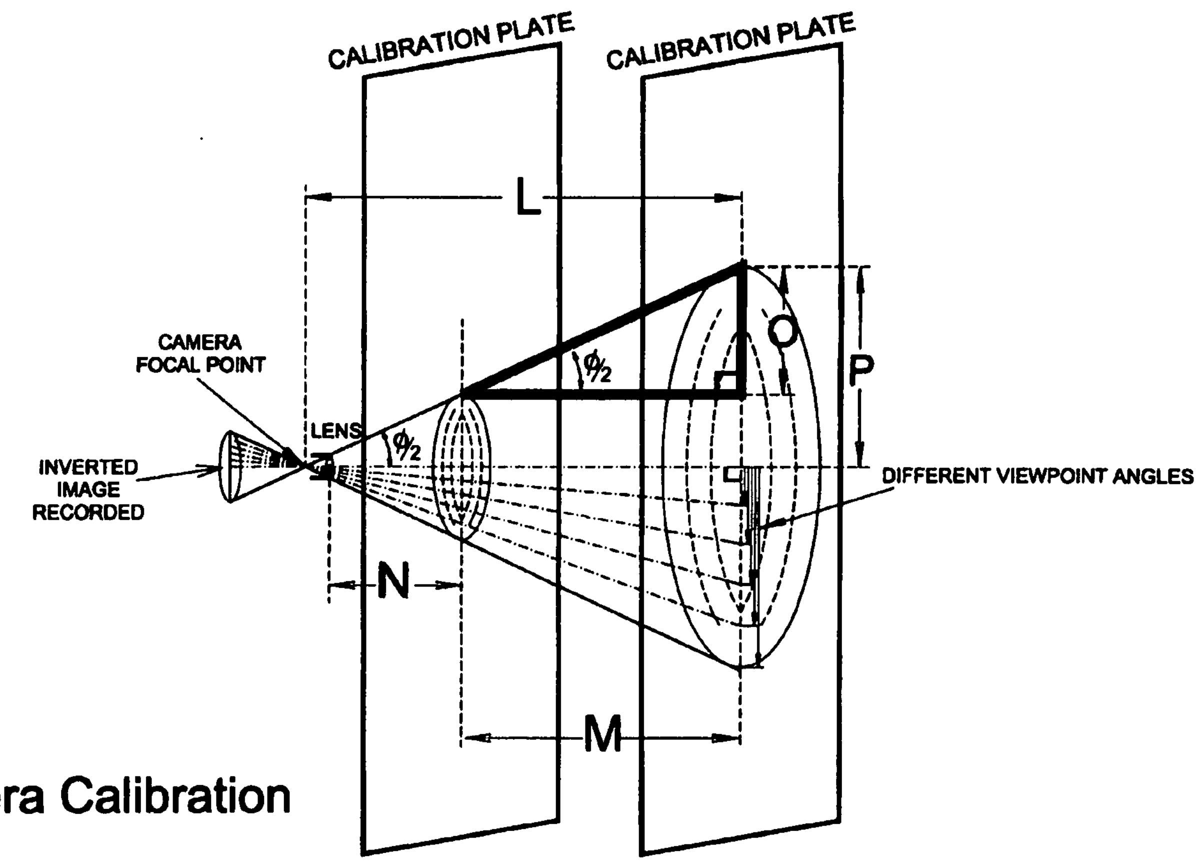


Plate 10 - Camera Calibration

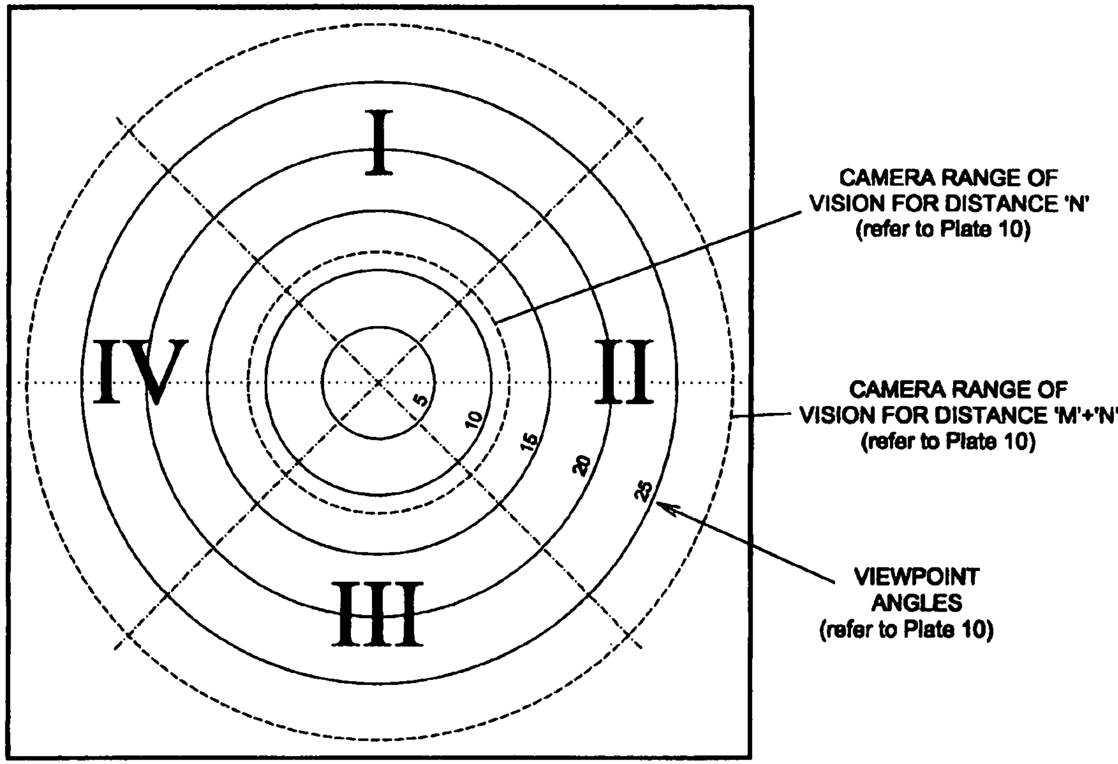


Plate 11 - Calibration Plate Quadrants

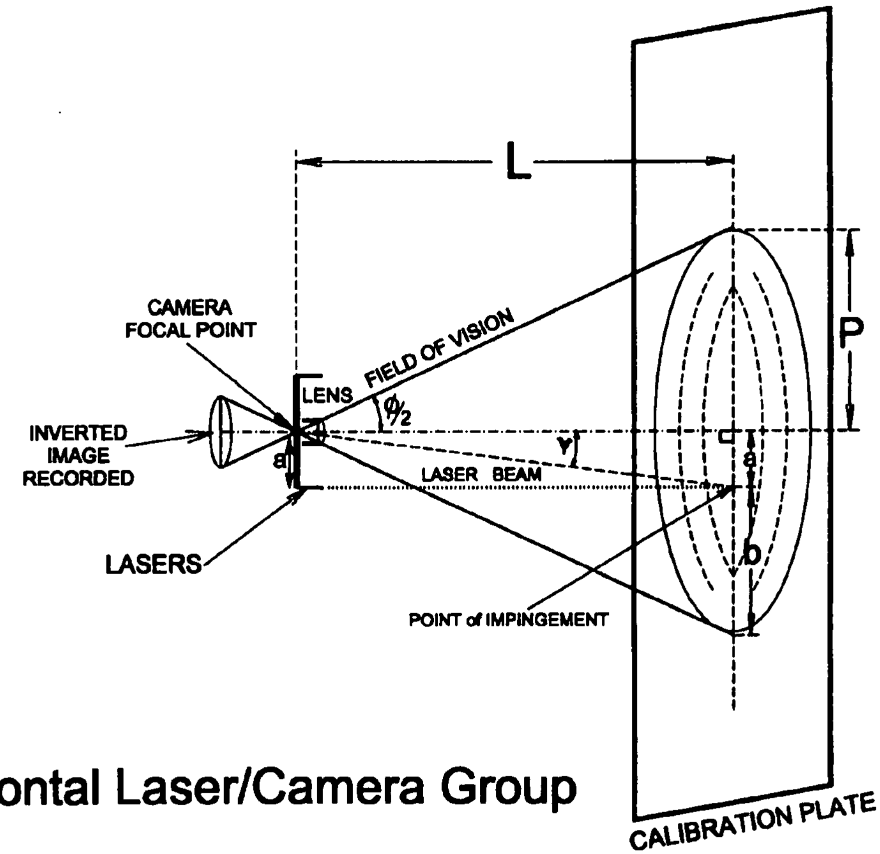


Plate 12 - Horizontal Laser/Camera Group

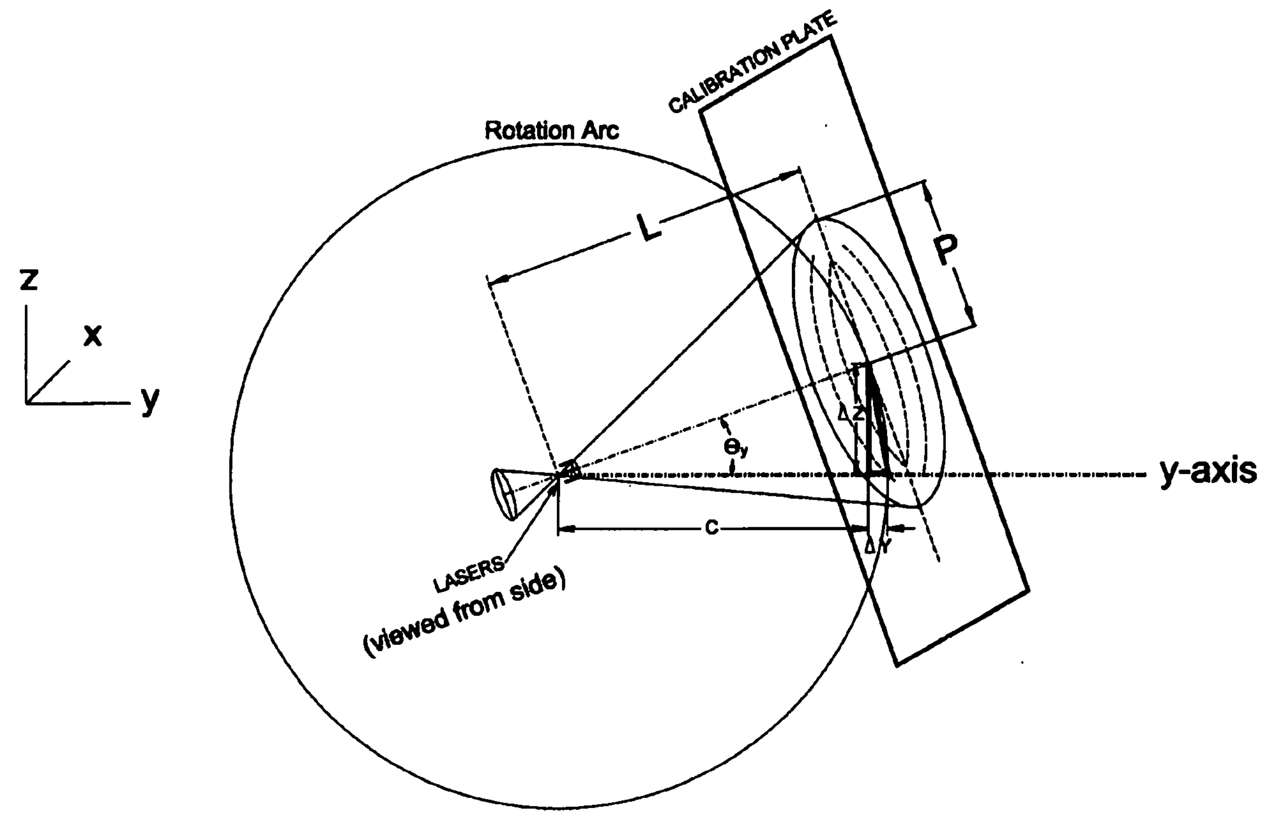
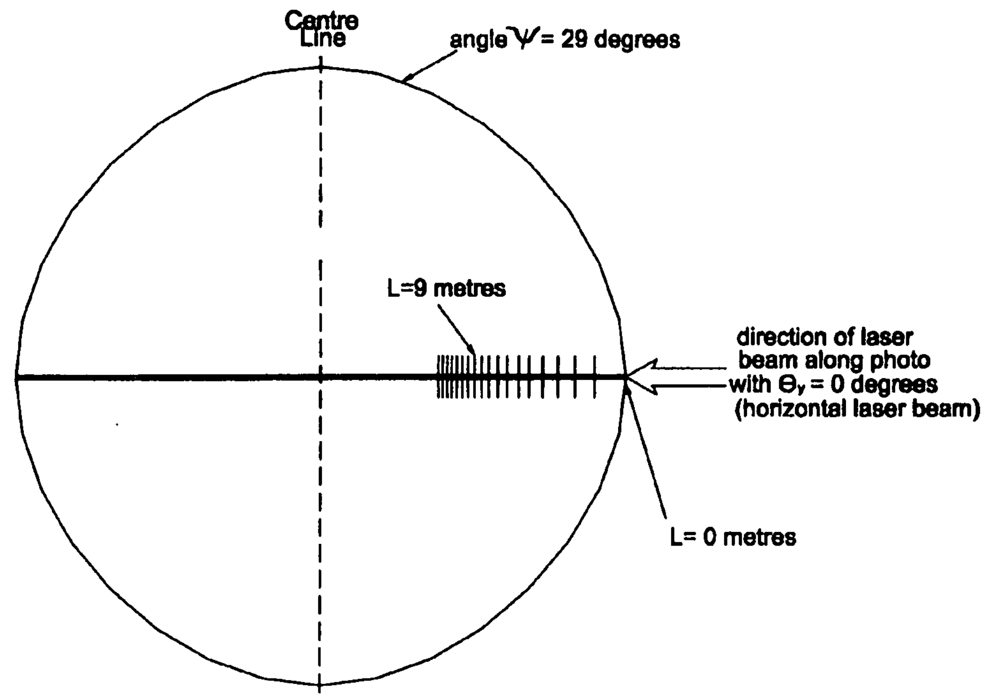


Plate 13 - Non-horizontal Group Direction



[Example]

Plate 14 - Calibration Plate with Movement of Laser Across Image for Equal Changes in Distance to Target

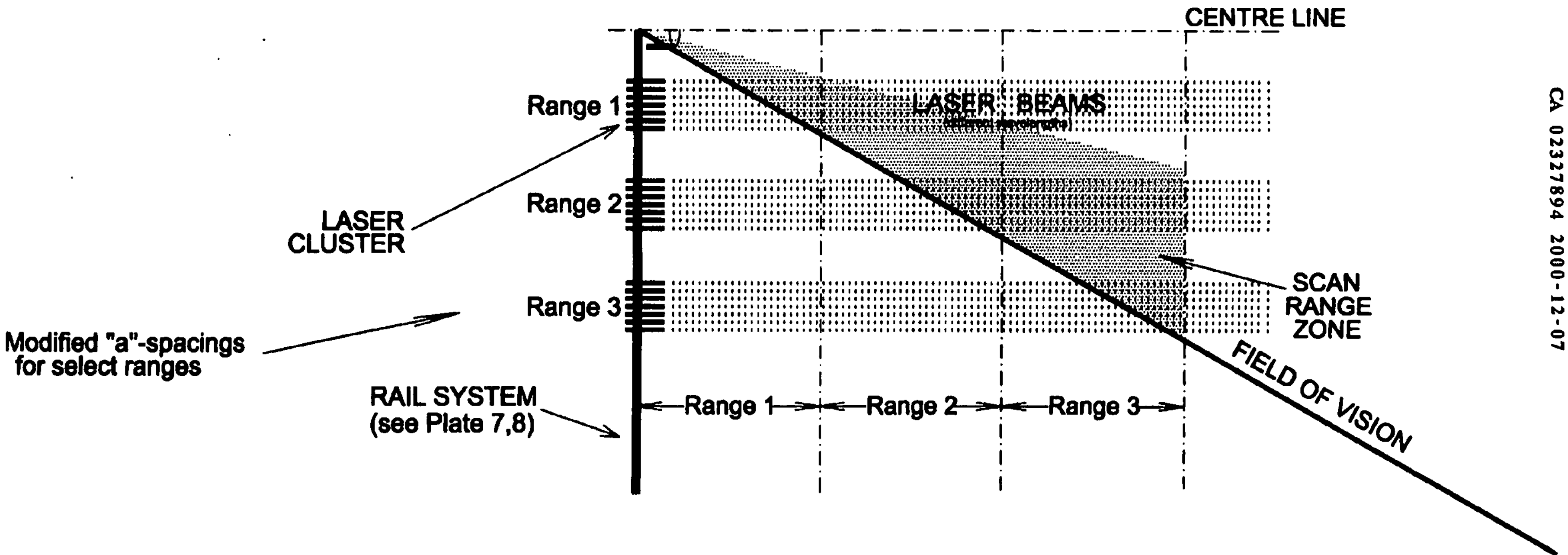


Plate 15 - Laser Scanning Ranges